

# CGS 3763: Operating System Concepts Spring 2006

## Memory Management – Part 4

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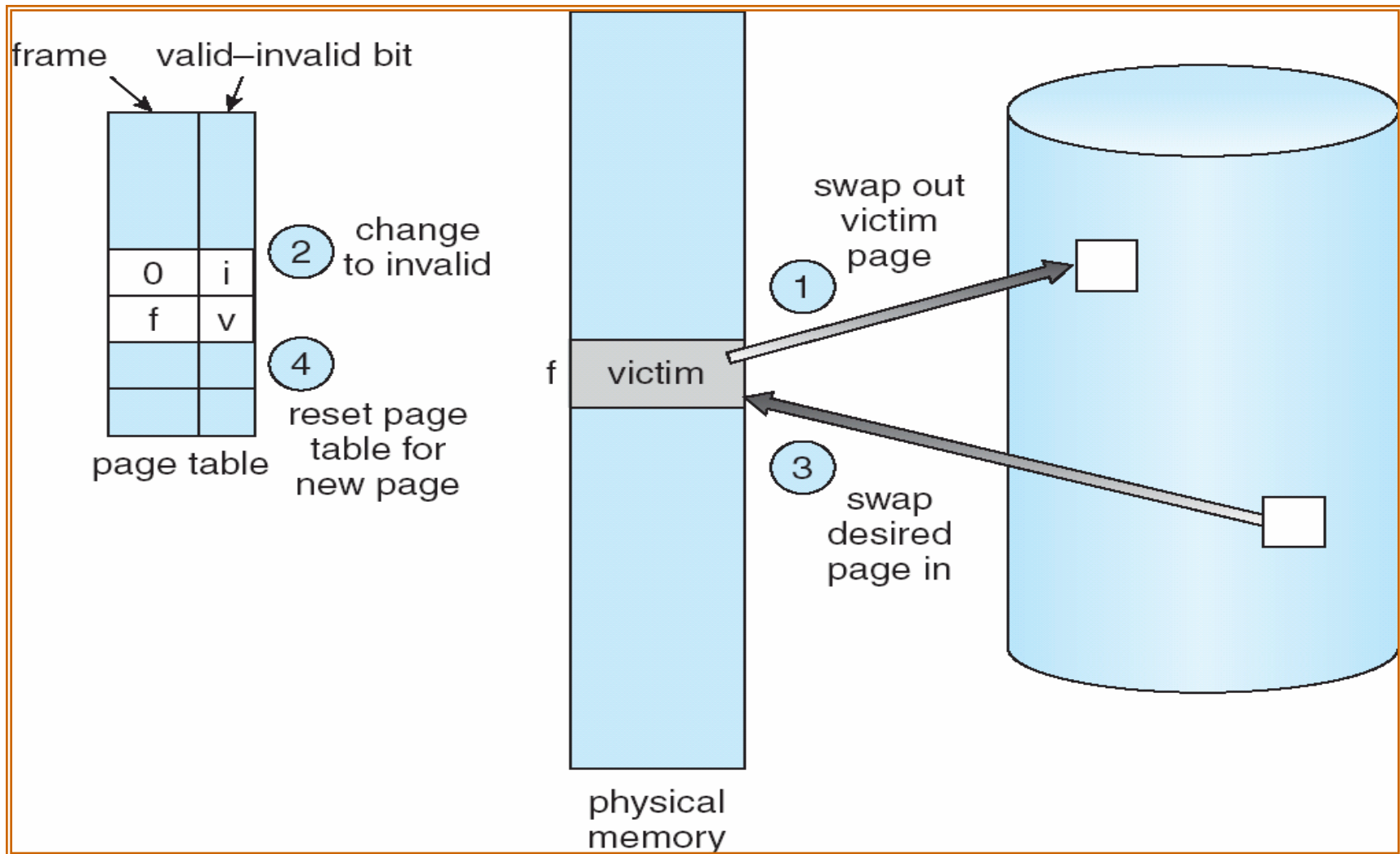


# Basic Page Replacement

1. Find a free frame:
  - If there is a free frame, use it
  - If there is no free frame, use a page replacement algorithm to select a **victim** frame
2. Bring the desired page into the (newly) free frame; update the page and frame tables
3. Find the location of the desired page on disk
4. Restart the process



# Page Replacement



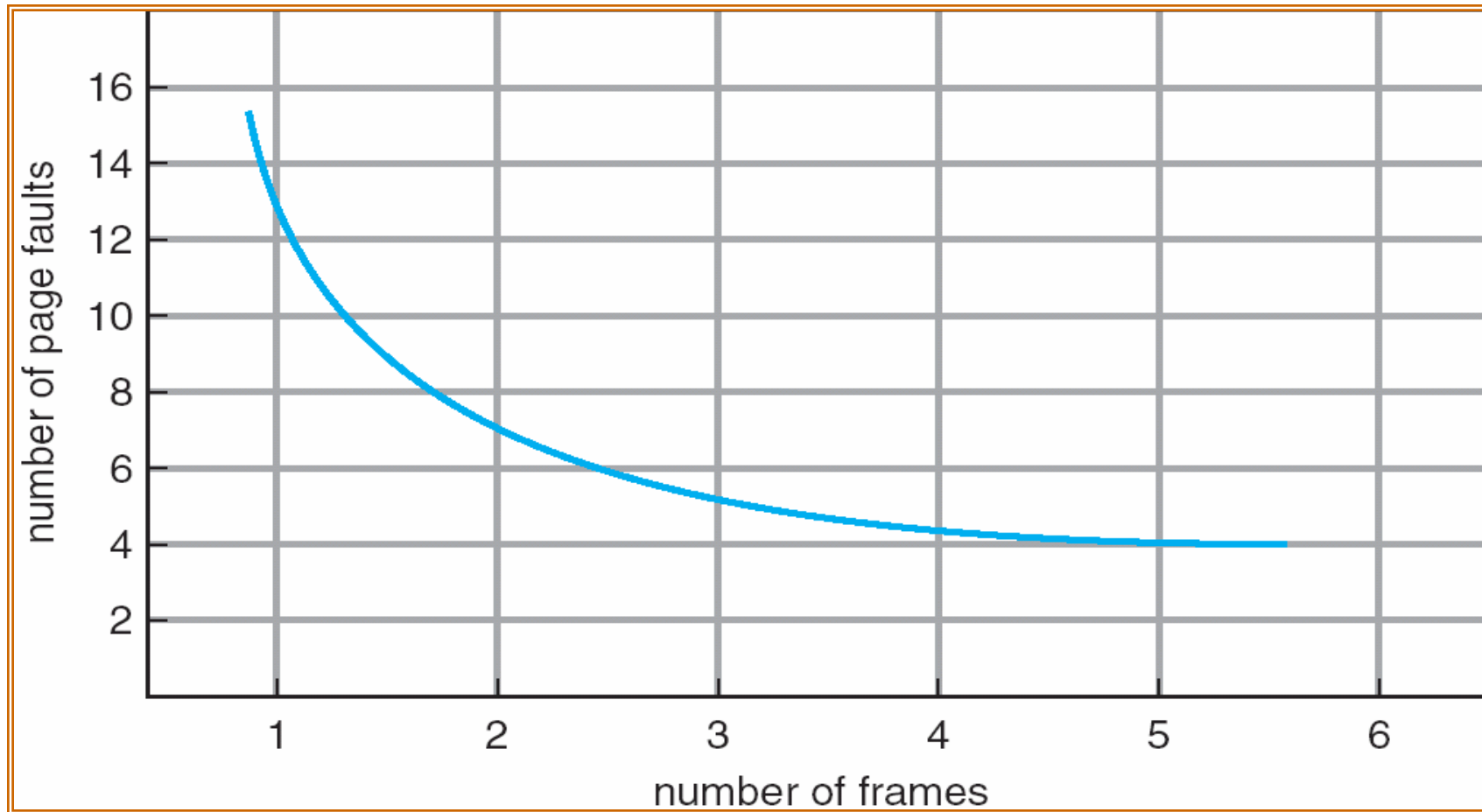
# Page Replacement Algorithms

- Want lowest page-fault rate possible.
- Evaluate algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string
- In many of the examples that follow, the reference string is:

**1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5**



# Graph of Page Faults Versus The Number of Frames



# First-In-First-Out (FIFO) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)

reference string

	1	2	3	4	1	2	5	1	2	3	4	5
1	1	1	1	2	3	4	1	1	1	2	5	5
2		2	2	3	4	1	2	2	2	5	3	3
3			3	4	1	2	5	5	5	3	4	4



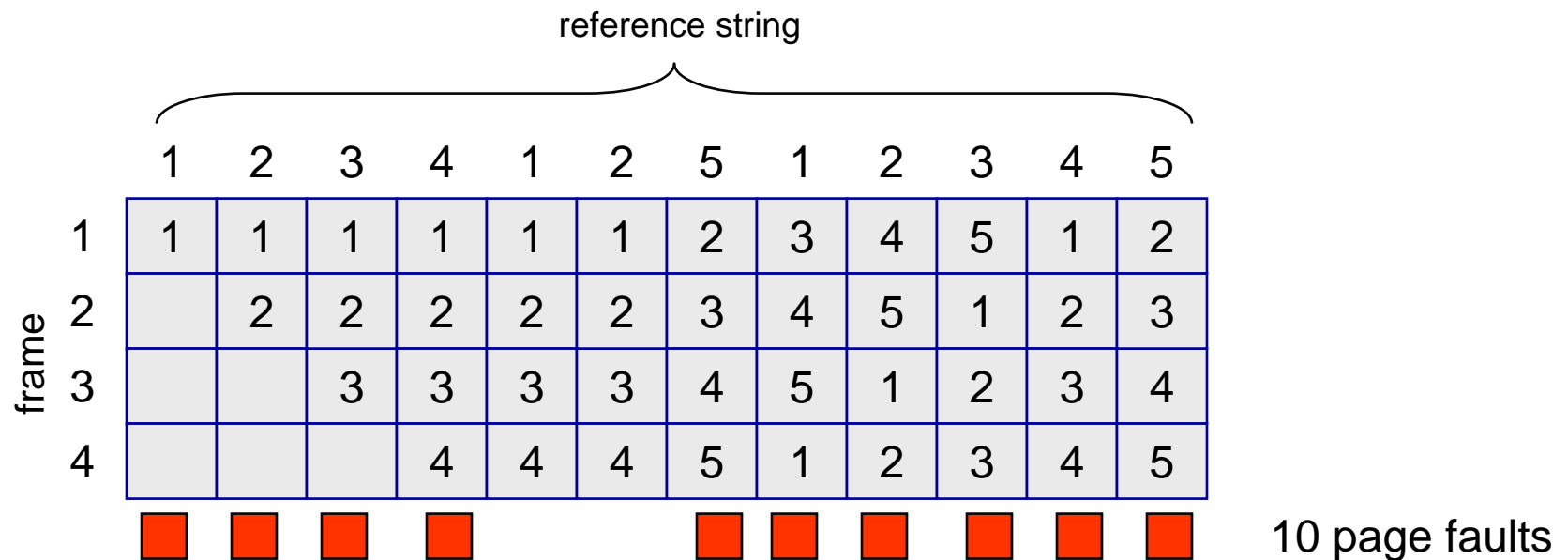
9 page faults

Indicates  
page  
fault has  
occurred



# First-In-First-Out

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 4 frames (4 pages can be in memory at a time per process)

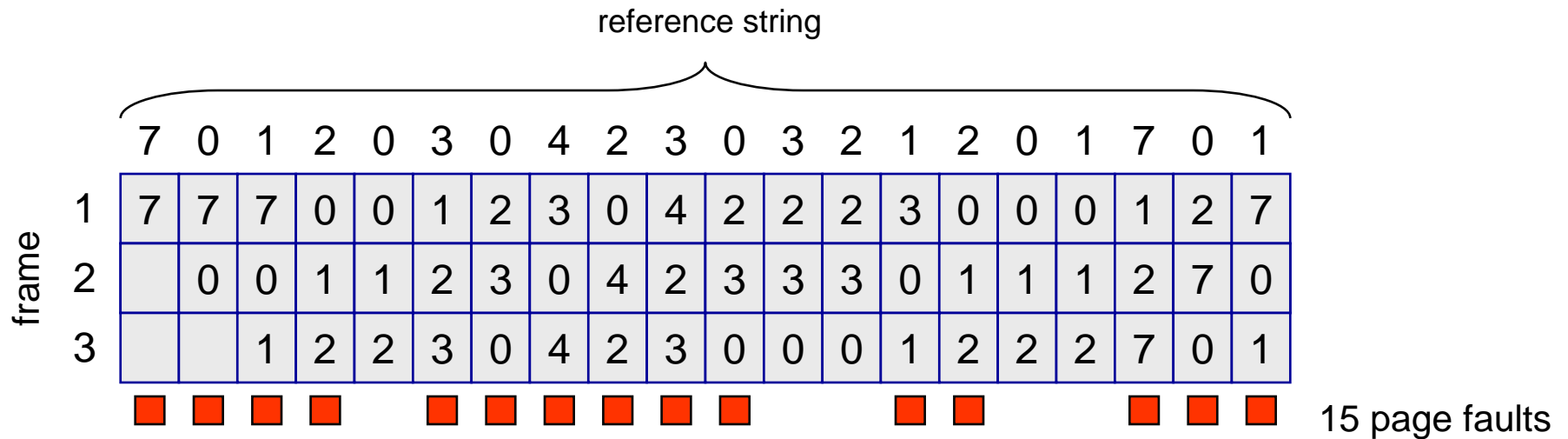


– Belady’s Anomaly: more frames  $\Rightarrow$  more page faults



# First-In-First-Out – Another Example

- Reference string: 7,0,1,2,0,3,0,4,2,3,0,3,2,1,2,0,1,7,0,1
- 3 frames (3 pages can be in memory at a time per process)



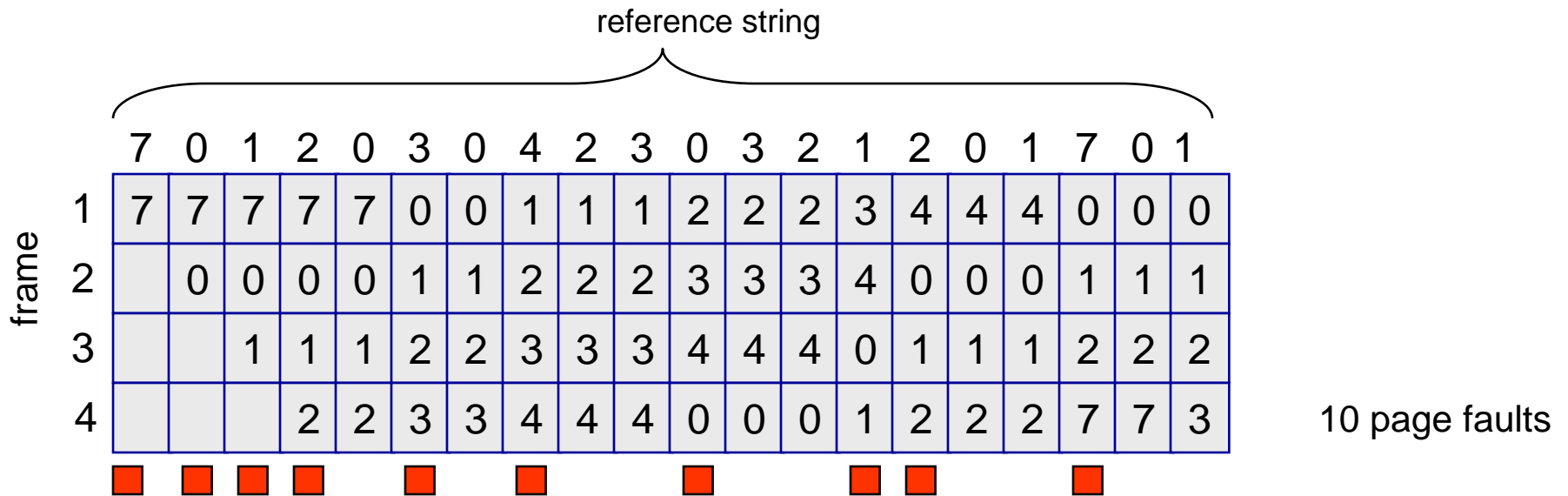
- Does this reference string exhibit Belady's Anomaly?





# First-In-First-Out – Another Example

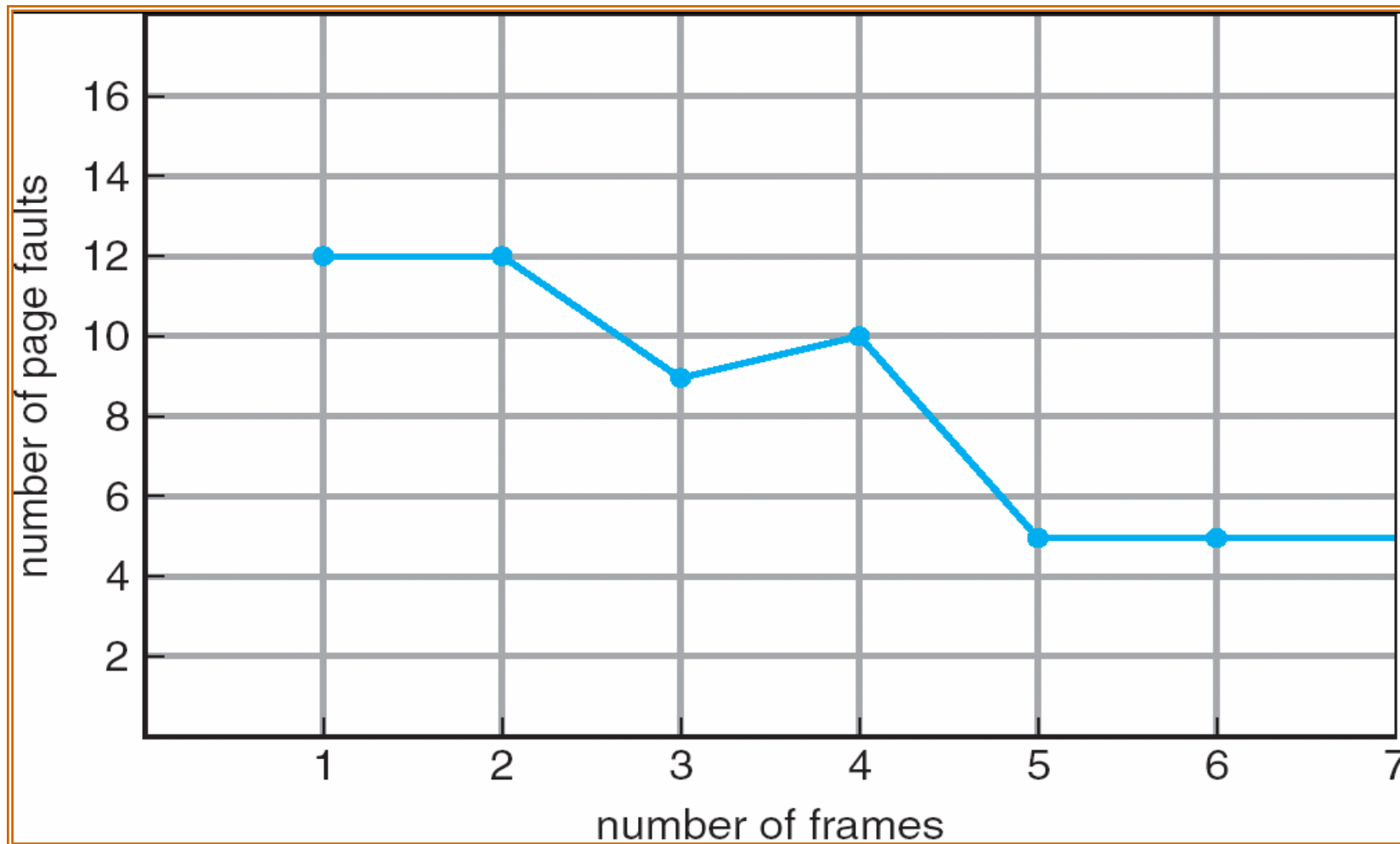
- Reference string: 7,0,1,2,0,3,0,4,2,3,0,3,2,1,2,0,1,7,0,1
- 4 frames (4 pages can be in memory at a time per process)



- Answer: No, at least not with 3 and 4 pages.



# FIFO Illustrating Belady's Anomaly



# Optimal Algorithm

- Replace page that will not be used for longest period of time
- 4 frames example

reference string

	1	2	3	4	1	2	5	1	2	3	4	5
1	1	1	1	1	1	1	1	1	1	1	4	4
2		2	2	2	2	2	2	2	2	2	2	2
3			3	3	3	3	3	3	3	3	3	3
4				4	4	4	5	5	5	5	5	5

■ ■ ■ ■ ■ ■ ■

6 page faults

How do you know this?

- Used for measuring how well your algorithm performs



# Optimal Algorithm – Another Example

- Reference string: 7,0,1,2,0,3,0,4,2,3,0,3,2,1,2,0,1,7,0,1
- 3 frames (3 pages can be in memory at a time per process)

reference string

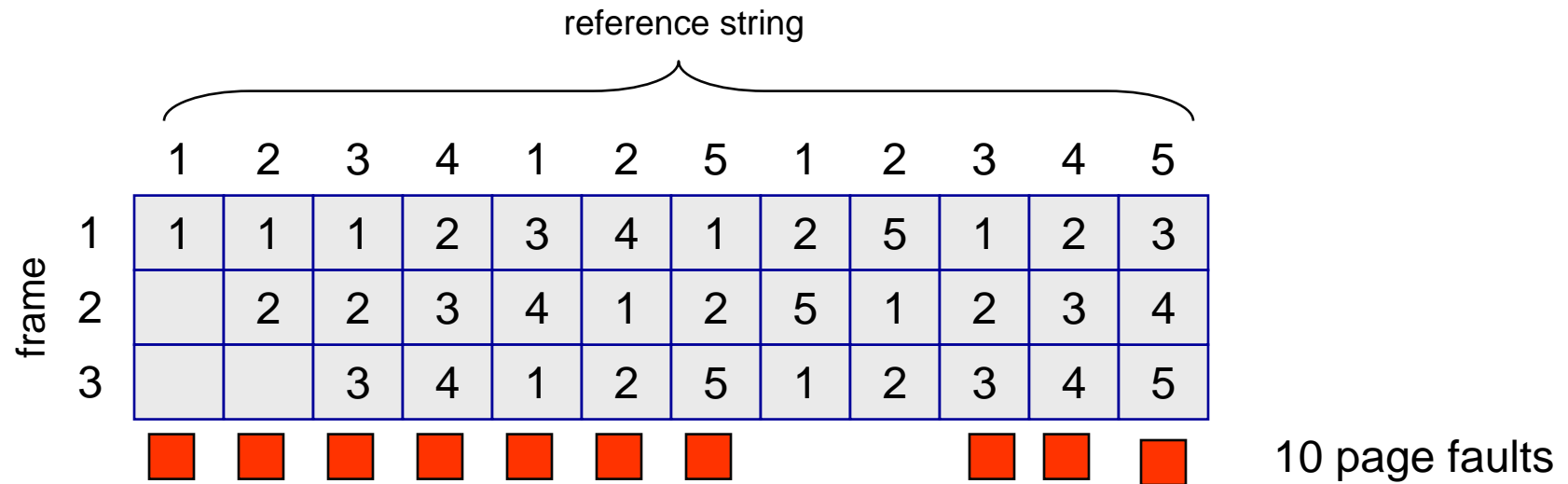
	7 0 1 2 0 3 0 4 2 3 0 3 2 1 2 0 1 7 0 1																				
frame	1	7	7	7	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	
	2		0	0	0	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	
	3			1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	7	7	7
		■	■	■	■		■		■			■			■				■		

10 page faults



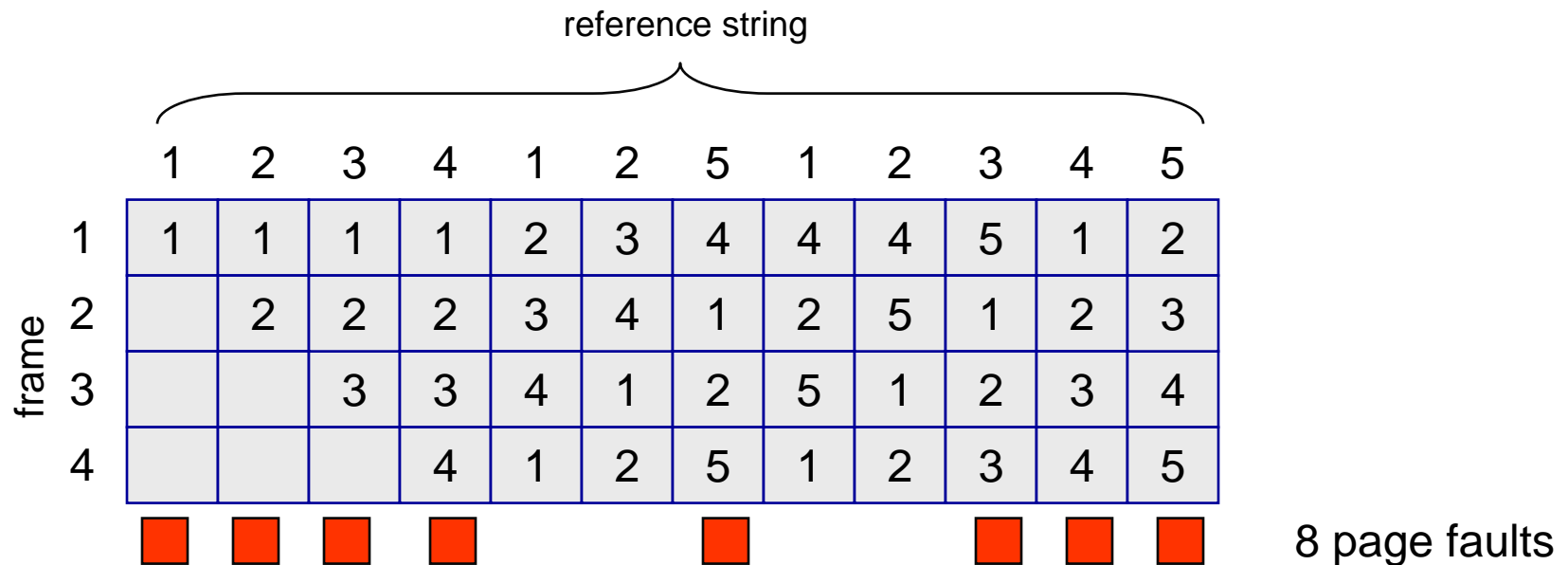
# Least Recently Used (LRU) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)



# LRU Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 4 frames (4 pages can be in memory at a time per process)



# LRU – Another Example

- Reference string: 7,0,1,2,0,3,0,4,2,3,0,3,2,1,2,0,1,7,0,1
- 3 frames (3 pages can be in memory at a time per process)

reference string

	7	0	1	2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0	1
frame 1	7	7	7	0	1	2	2	3	0	4	2	2	0	3	3	1	2	0	1	7
frame 2		0	0	1	2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0
frame 3			1	2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0	1

■ ■ ■ ■      ■      ■ ■ ■ ■      ■      ■      ■

12 page faults

- Does this reference string exhibit Belady's Anomaly?



# LRU – Another Example

- Reference string: 7,0,1,2,0,3,0,4,2,3,0,3,2,1,2,0,1,7,0,1
- 4 frames (4 pages can be in memory at a time per process)

reference string

		7	0	1	2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0	1
frame	1	7	7	7	7	7	1	1	2	3	0	4	4	4	0	0	3	3	2	2	2
	2		0	0	0	1	2	2	3	0	4	2	2	0	3	3	1	2	0	1	7
	3			1	1	2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0
	4				2	0	3	0	4	2	3	0	3	2	1	2	0	1	7	0	1

■ ■ ■ ■      ■      ■      ■      ■

8 page faults

- Answer: No, at least not with 3 and 4 pages.

